

## POTENTIAL CROPS FOR DRAIN WATER REUSE

There are crops presently grown in the Westside San Joaquin Valley that would lend themselves for either direct drain water reuse or in combination with good quality water. It would be more convenient for growers to adapt drain water reuse practices on crops they are currently producing, than to introduce halophyte species such as *allenrolfea*, kenaf, *salicornia* and *atriplex*. *Salicornia* and *atriplex* will be discussed because extensive research and trials have been made.

Cotton already extensively grown may be irrigated with water having the salinities common to drain water, which is available in large portions of the valley. Rather than using high quality water after the plant has passed its early growth stages farmers could utilize available drain water. Sugar beets, safflower, pistachios, small grains, some vegetables and forages would also be available for irrigation with the drain water. Forages appear to have a great potential for drainage water reuse, since the vegetative mat they produce protects the soil surface from crusting during the winter rains and perennial grasses do not need to be started from seedlings each year.

There are economically grown salt-tolerant plants that have not been included in this presentation because they may not be frost tolerant, or have other growth characteristics that would make them unsuitable for the San Joaquin Valley. An example of this is date palm with a threshold salinity of  $EC = 4.0 \text{ dS/m}$  and a slope of 3.6 % yield decline per unit EC. There are others that could be mentioned.

What follows is a discussion of these salt tolerant crops and some of the recent research. Boron tolerance information is also provided in the discussion.

## Cotton

Cotton, a variety of plants of the genus *Gossypium*, belonging to the Malvaceae family and native to most subtropical parts of the world, has been producing fiber for mankind about six thousand years. Its first known cultivation was in the Indus valley about 4000 B.C.E. The centers of origin are believed to be Indo-China and tropical Africa in the Old World. Asiatic cottons have thirteen chromosomes (Martin and Leonard, 1949).

*Gossypium* is also native to South and Central America and in the western hemisphere it was used for clothing and rope in Peru and Mexico. There is evidence in a cave in New Mexico that irrigated cotton may have been grown in the Rio Grande valley approximately 300 B.C.E. (Anonymous, 2000) The modern varieties used in the United States appear to be derived from these cottons. Upland cotton, *G. hirsutum*, has creamy white flowers and a fiber length of  $\frac{3}{4}$  to  $1\frac{1}{4}$  inches. Sea Island and/or American Egyptian cotton, *G. barbadense*, has yellow flowers with a purple center spot and fiber length between  $1\frac{1}{2}$  and 2 inches (Martin and Leonard, 1949). These cottons have 26 chromosomes. When cotton cultivation moved into the irrigated valleys of the western United States the primary variety was Acala. The large flowers attract insects and the plants are easily cross pollinated so it is difficult to maintain pure varieties.

In the San Joaquin Valley (SJV) of California the primary cotton varieties included in the 1999 field trials were "Approved Acalas", "Approved Pimas", "CA Uplands", "CA Pima" plus other experimental varieties. (Hutmacher et al., 2000) Acala varieties CPCSD Maxxa and Phytogen-33 were grown for comparison purposes. It should be noted that the trials did not include all varieties approved for use in the SJV. The Westlands Water District reported 127,340 acres of Acala/Upland varieties and 75,980 acres of Pima varieties for the 1999 crop year. This constitutes nearly 35% of the total acreage planted to crops in the Westlands in 1999. (Westlands Water District, 1999) In the Tulare Lake basin the main crops are cotton and safflower and from personal observation acreage of cotton is also quite high in western Kern County.

It has long been known that cotton is very tolerant to saline/sodic soil conditions. In the two part linear equation developed by Maas and Hoffman (1977) cotton lint was given a threshold value  $EC = 7.7$  dS/m a slope of 5.7% per dS/m. (See detailed discussion of the Maas Hoffman equation in the scientific section of this paper.) This is important when considering drainage water reuse, since relatively high yields may be obtained by irrigating with the drainage water which can have  $EC = 6$  to  $12$  dS/m.

Grattan (1994) cites cases in Israel where cotton is grown using irrigation water of 4.6 dS/m and in Uzbekistan with  $EC_w = 7.8 - 9.4$  dS/m.

In a case reported by Wichlens et al. (1988a) irrigators in the Broadview Irrigation District in the SJV obtained good quality canal water in 1957. During subsequent years they installed drainage tiles to nearly 80% of the lands in the district, but had no outlet for their drainage system. The district began blending drainage water back into the irrigation supply. By 1983 the drainage water had increased in salinity to 2800 mg/l TDS. Although the fields were leached, the blended irrigation water reapplied to the land caused a shift in production from salt-sensitive crops to cotton. Cotton acreage doubled from the 1968-72 period to the 1978-82 period, while the tomato acreage decreased by 70%. During the same period Fresno County overall had increases in both cotton and tomato acreage. The point to be made is that growers were able to grow cotton on a district wide basis by blending drainage water into the irrigation supplies. Yields of cotton lint, on a per acre basis, actually increased by ten percent during the period cited above.

Rhoades and LeMert (1982 unpublished) blended 9 dS/m drainage water with 0.7 dS/m aqueduct water in the SJV. The 50/50 blend resulted in a 36% decrease in cotton lint yield when compared to the good quality water. Using the drainage water alone caused a 50% yield reduction from 1770 kg/ha to 900 kg/ha. However, using good quality water during the seedling stage and the blended drainage water thereafter resulted in only a 20% yield reduction. (cited by Shalhevet, 1984) This brings an important point to be made when using saline drainage water with cotton (or many plants). Seed germination appears to be a salt tolerant process; seedling emergence is salt sensitive.

Grattan (1994) cites Ayars et al. utilizing drip rather than surface irrigation methods used drainage water to irrigate cotton on a cyclic basis. For three consecutive years drainage water ( $EC_w = 8.0$  dS/m) was used for irrigation after seedlings were established. Subsequent to this wheat was planted and irrigated with good quality water  $EC < 0.5$  dS/m. Sugar beets were then planted after the wheat and again irrigated with the saline drainage water after the seedlings were established. This experiment resulted in no difference in yield from plots irrigated entirely with the good quality water.

Shennan et al. (1987) designed an experiment to test the long-term feasibility of using drainage water irrigation in a rotation of processing tomatoes and cotton. The study tested two designs of cyclic irrigation: 1) one year of saline drainage water ( $EC = 7.3-7.7$  dS/m, 5 mg/l B) applied to a tomato crop after first flower, followed by two years of aqueduct water applied to cotton crops; and 2) drainage water applied to tomato and the first cotton crop after pre-irrigation with aqueduct water and aqueduct water alone applied to the second year cotton crop. Each irrigation treatment began at the three points in the cropping sequence. After four years of investigation saline drainage water did not cause a yield decrease in the cotton or tomatoes (Grattan et al., 1991). However, in the fifth year the drainage water treatment did cause a reduction in tomato fruit yield (Grattan, 1994).

The above study did indicate that salt and boron had accumulated in the soil profile below 60 cm. Above 60 cm there is a yearly lag in salt accumulation and leaching. Grattan (1994) concluded that salt sensitive crops following salt tolerant crops could be adversely affected by the salinity in the soil profile in the year following irrigation with saline drainage water. It should be noted that there were no long-term detrimental effects on the yield of cotton lint in this experiment.

Mitchell et al., (2000) report on using cover crops and gypsum in the winter together with a cyclic reuse of drainage water in the cotton/tomato rotation. Saline water,  $EC = 6.9 \text{ dS/m}$  was used to provide 70% of the irrigation water for the two crops. There was no apparent loss in cotton lint yield during the third year of the rotation, but there was a 33% decrease in yield for processing tomatoes in the second year. Significantly, there were decreases in cotton seedling emergence and increased problems with seedling disease when the cover crops were utilized and incorporated. Soil  $EC_e$  increased from around  $2 \text{ dS/m}$  to approximately 6 during the three year period of this experiment.

Additional information regarding the possibility of using cotton as a salt tolerant crop in a drainage reuse scheme comes from Frenkel et al. (cited in Shalhevet, 1984). They had crop production functions for cotton as  $Y_r = 0.223 + 0.17D_i$  when the crop was irrigated with  $3 \text{ dS/m}$  water and as  $Y_r = 0.204 + 0.16D_i$  when the crop was irrigated with  $8 \text{ dS/m}$  water.  $Y_r$  is the relative yield and  $D_i$  is the quantity of irrigation water applied in mm.

Letey and Dinar (1986) also calculated crop production function for cotton dry matter production. Since their model was based upon the linear relationship between dry matter production and ET and the threshold salinity and slope of the two part equation were presented as cotton lint production, it was necessary to determine a relationship between cotton lint and cotton plant dry matter. The literature showed that this was not a linear relation but was a quadratic formula. For cotton dry matter production they provide a threshold of  $6.1 \text{ dS/m}$  and a slope of 6.9% for the two part equation. The result presented seemed to imply that higher lint yield may occur with the use of saline water as opposed to non-saline water. This was explained to occur because the saline water tends to inhibit vegetative growth at high values which in turn leads to higher lint production.

One problem encountered when using saline irrigation water in a sprinkler system is leaf damage to the crop. Grattan (1994) cites Maas et al., who sprinkled a cotton crop with a salt water mixture (60 eq/cubic meter sodium chloride plus sodium sulfate). They found no leaf burn on the cotton plants even though there was damage to other crops at this concentration. Benes et al. (1996) found that maize and barley could be sprinkled with saline water if non-saline water was used to wet the crop prior to the use of saline and then again to rinse the crop at the end of the irrigation period. This would only be feasible if there were immediate access to both saline and non-saline water for the sprinkler system.

In a related study which basically falls into source reduction instead of drainage water reuse Ayars grew cotton that was irrigated to become established and then forced to

use saline water from a shallow water table to meet the crop needs at the later stages of growth. They found that cotton grown by this method is capable of using water with higher salinities and soil saline conditions measured by the saturation extracts ( $EC_e$ ) than had previously been believed possible. Osterbaan (1982), in a field study in Pakistan also found that drainage below 60cm depth was unnecessary to grow cotton. Combinations of these type studies with drainage water reuse may enable growers in the SJV to profitably continue growing cotton on lands which are now considered nearly unsuitable for production.

Boron (B) must also be considered when choosing crops for irrigation with SJV drainage water. Fortunately, cotton is also listed as very tolerant to B (Maas and Grattan, 1999; Hanson et al. 1999) with threshold values boron concentration of 6.0 – 10.0 mg/L, after which yield reduction occurs. Data was not available on the slope of the yield reduction. Eaton (1944) found 130% more growth when plants were irrigated with B concentration in the 5 to 15 ppm range when compared with plants grown when B concentration was 1 ppm or less. Best growth occurred at the 10-ppm concentration. Eaton noted deficiency symptoms when plants were grown with only 0.03 to 0.04 ppm B in the solutions, thus it is not an actual nutrient deficiency problem in the 1 ppm solution.

## Sugar Beets

From a listing by Maas and Grattan (1999) sugar beets (*Beta vulgaris*) is one of the most salt tolerant of the regular crops grown in the San Joaquin Valley of California. The threshold salinity is given as 7.0 dS/m and the slope of the two part equation is 5.9 % per dS/m which is comparable with cotton. Letey and Dinar (1986) show that irrigation water salinities in the range of 11 dS/m will still provide 90% yield for sugar beets. Ayers and Westcott (1976) have noted that salinity in the germination area of sugar beets should not exceed 3 dS/m, thus placing caution in early season use of saline water.

Sugar beets are a relatively new field crop compared to some, which have been grown by mankind for thousands of years. Beets have been grown and were eaten for their sweetness many years prior to 1747 when the German chemist, Marggraf, found the sugar in the beet was sucrose, the same as that found in sugar cane. Louis Vilmorin of France then selected beet progeny for their sugar content raising the percentage sugar from about 7.5% up to 16-17%. (Martin & Leonard, 1949)

The first successful commercial factory in the United States was erected at Alvarado, California in 1870. Sugar beet culture spread throughout the irrigated valleys of the west and into the coastal plains of the Great Lakes region. They are primarily grown in a climatic belt where the summer mean temperature ranges from 67 to 72 degrees F which contributes to the maximum sugar content. Sugar beets are the only feasible sugar crop grown in cool climates and in the southern valleys of California and Arizona the crop is grown as a winter crop. In 1999, there were 7,432 acres of sugar beets grown in the Westlands Water District. (WWD Crop Report, 1999)

In the SJV, sugar beets may be planted in October to November, grow to maturity from December to April and mature for harvest thereafter. This time period lends itself to application of saline drainage water for irrigation at a time when the water levels in the soil are high and drainage water disposal is a problem. Studies have shown that the drainage water in the SJV can be used to irrigate the crop, but should be used after the seedling establishment period. A concern that has arisen and must be addressed is the problem of nitrates in the drainage water and residual nitrate in the soil profile. If nitrates are too high during the period of maturation sugar beets will have a lower sugar content.

Specifically, in the Imperial Valley of California, Rhoades et al., (1988) applied saline drainage water (TDS = 3500 mg/l) to sugar beets as a part of a melon, wheat, sugar beet rotation. The crop was established using Colorado river water (TDS = 900 mg/l) but the saline drainage water provided nearly 75% of the total crop irrigation requirement. Using the drainage water caused no decrease in yield when the crop was compared with checks receiving only Colorado River water. In another experiment, Kaffka et al. (1999) irrigated sugar beets with shallow saline groundwater pumped at the Westside Field Station in Five Points, CA. Boron (B) must also be considered when using SJV drainage water for reuse. Sugar beets are tolerant of B concentrations in the soil solution up to 4.9 mg/l before a decrease in yield is noted.

## Small Grains

The small grains barley, rye and triticale have been shown to be tolerant to salt and may have utility in a drainage reuse system. Most data shows wheat as moderately tolerant (Maas and Grattan, 1999) but semidwarf and durum wheat are shown as tolerant. Oats are less salt tolerant but may also be considered as possible forage crops in a drainage reuse system using blending. One advantage of the crops from the family is that they can be planted in the fall and utilize the saline drainage water in the winter and spring when the greatest quantity of the drainage water is available. A disadvantage is that these crops require only small applications of water for growth and maturation and that their water requirements are often met by normal rainfall and water stored in the soil profile. These crops are also on the low end of the economic return scale in agriculture. Barley can yield 100 bu/acre and can economically compete with corn in providing nutrients for animal production.

**Table 7: Salt tolerance of small grains based upon the two part linear equation (Maas and Grattan, 1999)**

Crop		Electrical Conductivity of Soil Saturated Extract		Rating
Common name	Scientific name	Threshold dS/m	Slope % dS/m	
Barley	<i>Hordeum vulgare</i>	8.0	5.0	T
Oats	<i>Avena sativa</i>			T
Rye	<i>Secale cereale</i>	11.4	10.8	T
Sorghum	<i>Sorghum bicolor</i>	6.8	16.0	MT
Triticale	<i>X Triticosecale</i>	6.1	2.5	T
Wheat	<i>Triticum aestivum</i>	6.0	7.1	MT
Wheat (semidwarf)	<i>T. aestivum</i>	8.6	3.0	T
Wheat, Durum	<i>T. turgidum</i>	5.9	3.8	T

Barley for forage has a threshold salinity of  $EC_e = 5.3$  dS/m and does not have a 50% loss in yield until  $EC_e = 13.0$  dS/m. Mass and Grattan (1999) found that barley is less tolerant during the seeding stage and the  $EC_e$  should not exceed 4-5 during this period. Barley grown for grain is even more tolerant of saline soil conditions.

There appears to be a wide variation in threshold salinity comparisons. Some additional data is presented in table 8 below.

**Table 8: Threshold Salinity Comparisons by Various Researchers after Meri (1984)**

Researchers	Barley (g)	Barley (f)	Wheat (g)	Oats (g)
Maas & Hoffman (1977)	8.0	6.0	6.0	-
Hoffman & Van Genuchten (1982)	5.5	4.6	7.0	5.8
Rhoades & Merrill (1976)	5.4	5.3	5.9	5.1

Prior to use of drainage water for reuse one must also consider boron concentration in the irrigation water and the tolerance of plants to boron. (See discussion of B elsewhere in this report.) See Table 9 below showing boron tolerance for the small grains discussed above:

**Table 9: Boron tolerance of small grains**

Crop	Tolerance based on:	Maximum concentration in soil water in mg/l Threshold value	Boron tolerance rating
Barley	Grain yield	3.4	MT
Oats	Grain (immature)	2.0-4.0	MT
Sorghum	Grain yield	7.4	VT
Wheat	Grain yield	0.75-1.0	S

Information was not available for rye or triticale. S – sensitive; MT – moderately tolerant; T- tolerant; VT – very tolerant. (Based upon Hanson et al., 1999)

Sprinkler irrigation with 60 eq/cubic meter (sodium sulfate and sodium chloride) water caused leaf burn on barley. Other small grain crops apparently were not tested.

In the Imperial Valley of California Rhoades et al., (1988) conducted field experiments to test the cyclic irrigation practice of applying saline drainage water for irrigation. He used wheat, sugar beets and melons in a two-year rotation. Colorado River water (900 mg/l TDS) was used for irrigation of the melons and for preplant and early growth of the other two crops. Drainage water (3600 mg/l TDS) was used for the remaining irrigations of wheat and sugar beets supplying approximately 75% of the total water needs. After two years there was no reduction in yield for the saline irrigated crops when compared with a similar rotation irrigated only with Colorado River Water.

Wheat was also used in a rotation experiment in the San Joaquin Valley, but it was irrigated only with good quality water (EC <0.5 dS/m) even though other crops in the rotation were irrigated with saline drainage water. (Ayars et al., 1986a,b) There are indications that flour made from wheat irrigated with saline water is of higher quality than wheat flour from normal irrigations.

It would appear one research need is to conduct an experiment in the San Joaquin Valley testing the possibility of using saline drainage water directly to irrigate small grain crops during the winter season. It may be necessary to have a preplant irrigation with non saline water to improve germination and early seedling growth if the drainage water to be used has EC > 4.0 dS/m. A study also could be made on the economic returns of barley irrigated with saline drainage water compared with corn grown with non-saline water. Perhaps the saline water/barley combination could replace corn in feed thus reducing the requirement for good quality water to grow this low value crop.

The origins of barley have not been well defined. It is known that the first writing in Sumer lists barley. It is widespread and common in early Neolithic sites, including Ali Kosh in the south Iranian Deh Luran Plain, Jarmo in the Zagros Mountains, Catal Huyuk in Anatolian Turkey and Beidha in the southern Jordanian rift (Renfro, 1973). Naturally wild barley, *Hordeum vulgare* var. *spontaneum*, is the most wide spread of the cereals, growing in the hills of the Levant, Turkey, the Zagros and even into the western Himalayas and Tibet. The wild varieties seem to prefer the hotter steppe and desert, but modern varieties have been widely adapted to climate and soil differences. Two domestic cultivars, six row *H. vulgare* and two row *H. distichum*, are grown in the modern era. All have fourteen chromosomes.

Several archeological sequences in the Near East, including Deh Luran Plain in Iran, have more equal amounts of wheat and barley in the earliest sequences. Later, as we approach more modern times the proportion of barley tends to increase and this has been attributed to the over irrigation and salinization of the soils. (Hole and Flannery, 1967) Perhaps the salt tolerance observed in the species is due to genetic selection over thousands of years.

The history of wheat is even more complex than barley. Emmer, a type of wheat is found in Egyptian tombs and is also known in historic Greece, Persia, and Turkey. Einkorn is another early form of wheat, having seven chromosome pairs as compared to emmer with fourteen (Martin and Leonard, 1949). Modern genetic studies have begun to unravel wheat history by actual study of the gene sequencing. Cytogenetic studies indicate that emmer, *Triticum turgidum* subsp. *Dicoccum*, forms the ancestral stock for the modern high yielding bread wheat, *Triticum aestivum*. This latter grain has crossed with *Aegilops squarrosa*, having natural range from eastern Turkey to Azerbaijan through Pakistan (Renfrew, 1973). It is believed that the modern bread wheat could not have been formed naturally and is believed to be a product of domestic agriculture.

Rye, *Secale cereale*, originated in Turkestan and was unknown to the Egyptians and Greeks. *S. anatolium* is a wild form from Syria, Armenia, Persia, Afghanistan, Turkestan and the Kirghiz steppe. *S. montanum* is a wild form from southern Europe. It is believed that cultivation of this plant originated as a weedy mixture in the cultivated wheat and barley fields (Martin and Leonard, 1949).

Crosses between rye and wheat probably occurred naturally, but the offspring were usually weak non-productive plants. By selective breeding in Europe during the period 1870- 1930 some rye wheat crosses were developed that became agriculturally useful. During the 1930's the name triticale was first used for some of these crosses. The name did not catch on with the public until an episode of Star Trek in the 1960's used the grain in intergalactic trade.

## Safflower

Safflower (*Carthamus tinctorius*) is an annual, erect, glabrous herb, one to three feet in height with substantial branching. Flowers can be white, yellow, orange or red. The seed is smooth, four angled, white or cream colored and resembles a small sunflower seed. Safflower seed weighs 30 to 48 pounds per bushel with good quality seed weighing at 45. The whole seed contains oil, which is the main product for which the plant is grown. The residual meal after the oil has been pressed can be used for animal feed and is comparable to cottonseed meal in quality. Historically a red dye was extracted from the flowers in India that may have contributed to the species name. The plant was grown agriculturally in Egypt 3500 years ago.

Safflower is a salt tolerant plant, which does not have a fifty percent yield loss until the  $EC_e$  reaches 15 dS/m (Maas and Grattan, 1999). Data for the two part equation for relative yield was not available in the literature, but one source provides a threshold value of  $EC_e = 5.3$  dS/m with 10% yield loss at 8.0; 25% yield loss at 11.0; and 50% yield loss at 14.0 dS/m (Utah State University Extension,). Ayers and Westcott (1976) reported a 10% yield loss at  $EC_e$  6.2 dS/m; 25% at 7.6 and 50% at 9.9. Bernstein (1964) assessed the salt tolerance of the plant in plots in Riverside, California finding it to be moderately tolerant. Raines et al. (1987) grew safflower in successive rotational cycles in the San Joaquin Valley with each successive cycle increasingly salinized. This experiment showed (1) decreasing yields with increasing salinity and (2) attributed the yield decrease to both reduced plant growth and a reduction in plant stand.

Kaffka and Bassil (1999) state that the Rains et al. (1987) experiment did not adequately document the salinity conditions in the soil and water for the safflower experiment. He is studying a safflower/sugar beet rotation on plots at the UC Westside Research and Extension Center. Plots are furrow irrigated with CVP high quality water ( $EC_i < 1$  dS/m) or saline water ( $EC_i = 6.7$  dS/m) from a shallow well located on site. Seven plots are irrigated one year with high quality water and the following year with saline water, or vice versa. These cross-over plots represent moderate saline conditions. The soil has been sampled to a depth of 2.7 meters and moisture conditions are tracked during the growing season with neutron probes.

Results from the 1998 growing season follows: Effective  $EC_e$  was estimated to be 2.1 dS/m for the control plots and 7.2 dS/m for the saline plots. Consumptive water use (ET) between April and July averaged 515 mm in the control plots and 435 mm in the saline plots. Seed yield was not correlated with water use over the range 400 to 580 mm, but total dry weight and height of plants directly correlated with water use. This implies that saline conditions reduced plant size, but did not affect harvestable yield. The oil content was slightly increased in the saline plots. Kaffka and Bassil (1999) concluded that safflower tolerated salinity, without yield loss, better than reported previously. It should be noted that both 1997 and 1998 had rainfall amounts greater than normal for this area of the SJV. Kaffka also reported that the early part of the 1998 growing season was unusually cool due to the El Niño climate pattern.

In the Tulare Lake Drainage District cotton and safflower are the two main crops grown on the undrained heavy clay soils of the basin. Safflower is a deep-rooted plant with the ability to dry out the soil profile when it becomes over saturated. Growing safflower allows the growers to plant cotton and have economic returns where drainage systems are not available in the heavy clay soils of the Tulare Lake Basin. (Doug Davis, personal communication)

## Vegetables

Vegetables listed in the 1999 Westlands Water District Crop Acreage report are: artichokes, asparagus, beans, broccoli, cabbage, carrots, cauliflower, sweet corn, cucumbers, garlic, lettuce, melons, onions, peppers, spinach, and tomatoes. This provides a listing of potential crops that are acclimated to the SJV. However, with the exception of asparagus, most vegetable crops are not salt tolerant. See table below:

**Table 10: Salinity and Boron Tolerance of Vegetables**

Crop	Threshold Salinity dS/m	Slope	Rating for Saline Tolerance	Boron Tolerance based on	Maximum concentration in soil water in mg/l	Boron Tolerance Rating
Artichoke	6.1	11.5	MT	Laminae DW	2.0-4.0	MT
Asparagus	4.1	2.0	T	Shoot DW	10.0-15.0	VT
Beet (red)	4.0	9.0	MT	Root DW	4.0-6.0	T
Broccoli	2.8	9.2	MS	Head FW	1.0	MS
Cabbage	1.8	9.7	MS	Plant DW	2.0-4.0	MT
Carrot	1.0	14.0	S	Root DW	1.0-2.0	MS
Celery	1.8	6.2	MS	Petiole FW	9.8	VT
Corn, sweet	1.7	12.0	MS			MT
Cucumber	2.5	13.0	MS	Shoot DW	2.5	MT
Eggplant	1.1	6.9	MS			
Garlic	3.9	14.3	S	Bulb yield	4.3	T
Lettuce	1.3	13.0	MS	Head FW	1.3	MS
Muskmelon	1.0	8.4	S	Fruit yield	2-4	MT
Onion bulb	1.2	16.0	S	Bulb yield	8.9	VT
Onion seed	1.0	8.0	S	Yield DW		
Parsley				Plant DW	4.0-6.0	T
Pepper	1.5	14.0	MS	Fruit Yield	1.0-2.0	MS
Potato	1.7	12.0	MS	Tuber DW	1.0-2.0	MS
Radish	1.2	13.0	MS	RootFW	1.0	MS
Spinach	2.0	7.6	MS			
Squash scallop	3.2	16.0	MS	Fruit Yield	4.9	T
Squash zucchini	4.7	9.4	MT	Fruit Yield	2.7	MT
Tomato	2.5	9.9	MS	Fruit Yield	5.7	T
Turnip	0.9	9.0	MS	Root DW	2.0-4.0	MT
Turnip greens	3.3	4.3	MT	Shoot DW		

The above table is taken from Mass and Grattan, 1999. The ratings: S – sensitive; MS – moderately sensitive; MT- moderately tolerant; T – tolerant; VT very tolerant

Tomatoes and melons have been irrigated with saline water (E.C. 8.0 dS/m and 6 mg/l B) and it was noted that fruit quality is improved (Shannon and Francois, 1978; Pasternak et. al., 1986). Processing tomatoes used in cyclic drainage water reuse schemes have also shown some promise as an economically viable crop for some drainage water reuse (Shennan et al., 1987). Other crops for which saline drainage water has been used for irrigation are: brassicas (cabbage, cauliflower), carrots, celery, onions, peppers, (Ayers and Westcot, 1985).

The chart for saline and boron tolerance for vegetables seems to indicate two important considerations 1) the combination of saline conditions and boron eliminate most vegetables from consideration for reuse and 2) that crops different from the ones tried above may offer potential for saline drainage water reuse. Prominent among those crops with both some tolerance for saline conditions and boron are: asparagus, red beets and zucchini squash.

Oster et al. (1999a) list asparagus as one of the salt tolerant forages in the group of warm season and cool season salt tolerant crops recommended for the SJV. Two hundred acres of asparagus was planted in the spring 2001 by Panoche Water District as part of their drainage water reuse program. In January 2001, while interviewing Mike Andrews of Rainbow Ranch, it was learned that asparagus is one of the main productive vegetable crops in his area of southwestern Kern county. He is installing an IFDM system for the purpose of eliminating his evaporation ponds. He had not anticipated using asparagus as a salt tolerant crop, but Abraham Meri, visiting from Israel, recommended that he try it, perhaps even in the third stage of drainage water reuse, i.e. using the drainage water from the salt-tolerant crop area to irrigate asparagus. Francois, (1987) indicated that asparagus is more tolerant of saline conditions after the first year of growth, thus it may be necessary to establish with non-saline water prior to irrigation with drainage water.

Sugar beets are grown commercially in the SJV and are recommended elsewhere as a portion of the drainage water reuse system. Red beets are not grown commercially and are somewhat less salt tolerant, but may have some potential as a drainage water reuse crop. Moderately salt tolerant squash could also be considered under certain circumstances.

## Forage Crops

Oster et al., (1999a) wrote, "saline-sodic drainage water likely is a resource for forage production along the land-locked, Westside of the San Joaquin Valley in California because many forages are salt-tolerant." The proposal included a combination of salt-tolerant crops for both the winter cool season and the summer warm season. The crops proposed for forage are small grains, sugar beets, brassicas, safflower and grasses. This would enable the livestock producer to have available both high energy and high protein feed on a year around basis.

Oster et al., (1999a) provided a table of potential salt tolerant crops listed in order of salt tolerance. The data is based upon Maas and Grattan (1999) and other research performed at the US Salinity Laboratory. The table is partially reproduced as table 11 below.

Other than testing the saline tolerance of these crops it would appear that not much actual data has been kept on applying drainage reuse water to these crops. Most of the data is anecdotal. The Jones ranch has been applying drainage water to Jose tall wheatgrass for several years, harvesting the crop and feeding it to cattle. They have not kept any data on quantities applied or yield data.

Other research on forages is just reaching points where actual data is to be generated. A portion of the salt-tolerant crop area at Red Rock Ranch has Jose tall wheatgrass and the area where eucalyptus trees were planted has now been converted to grass plots. Cervinka (personal communication) has reported that these plots were irrigated with non-saline canal water until May 2000. The species planted in these plots are: creeping wild rye (*Elymus* spp.), "Solado" alkali sacaton (*Sporobolus airoides*), Alta tall fescue (*Festuca elatior*), perla kolea grass (*Phalaris aquatica*), birdsfoot trefoil (*Lotus corniculatus*), Harding grass (*Phalaris tuberosa*), Argentine tall wheatgrass (*Agropyron elongatum*)(*Thinopyrum elongatum*), Jose tall wheatgrass (*A. elongatum*), puccinellia (*Puccinellia distans*), Alkar tall wheatgrass (*A. elongatum*), and saltgrass (*Distichlis spicata*).

Oster et al. (1999a) and Kaffka et al., (1999a,b) report on a forage project using small plots at the Westlake Farm in the SJV. Three warm season grasses, saltgrass (*Distichlis* spp.; NyPa Inc., Tucson, AZ), Bermudagrass (*Cyandon dactylon*, cv. Santa Ana) and seashore paspalum (*Paspalum* spp.) were first tested for saline tolerance at the US Salinity Lab. All three species grew well when irrigated with saline water up to 20 dS/m. Growth rates declined slowly when the salt concentration was increased above that level. In small test plots at the Westlake farm the same species were grown but over seeded in the fall with annual ryegrass or fescue. For total yield the best warm season/cool season forage mixture was Bermudagrass-ryegrass. The authors are continuing with a full field scale study at the Westlake farm but only preliminary data will be available for the 2000 season.

**Table 11: Listing of potential salt tolerant forages for the San Joaquin Valley drainage reuse systems.**

Forage Crop	Common name	Growth Season, Habit	Salt Tolerant Rating	Salt Tolerance Coefficients		EC <sub>e</sub> (70) dS/m	LR %
				Threshold slope			
<i>Puccinellia distans</i>	Puccinella		T			32	<10
<i>Distichlis spicata</i>	Saltgrass	Summer Perennial	T			>15	<10
<i>Paspalum vaginatum</i>	Alkali grass	Summer perennial	T			10-22 23	<10
<i>Asparagus officinalis</i>	Asparagus	Perennial	T	4.1	2.0	19	15
<i>Tritium aestivum</i> cv. Probred	Wheat	Winter Annual	MT	4.5	2.6.	16	15
<i>Tritium durum</i>	Durum wheat	Winter Annual	MT	2.1	2.5	14	20
<i>Agropyron elongatum</i>	Tall wheatgrass	Winter Perennial	T	7.5	4.2	15	20
<i>Beta vulgaris</i>	Sugar beet	Annual	T	7.0	5.9	12.	20
<i>Triticale</i> cv.Canabea	Triticale	Annual	T	8.1	8.8	12	20
<i>Festuca elatior</i>	Fescue	Winter				12	25
<i>Cynodon dactylon</i>	Bermudagrass	Summer	T	6.9	6.4	12	25
<i>Leptochloa fusca</i>		Summer Perennial	T	3.0	3.4	12	25
<i>Carthamus tinctorius</i>			MT			11	25
<i>Agropyron cristatum</i> cv. Fairway	Crested wheatgrass	Winter	T	7.5	6.9	12	25
<i>Agropyron sibiricum</i> cv. Standard	Siberian wheatgrass	Winter	MT	3.5	4.0	11	25
<i>Hordeum vulgare</i>	Barley	Winter	MT	6.0	7.1	10	30
<i>Sorghum sudanense</i>	Sudan grass	Summer	MT	2.8	4.3	10	30
<i>Festuca elatior</i>		Winter	MT	3.9	5.3	10	30
<i>Salsola iberica</i>		Annual	MT				
<i>Spartina</i> spp.	Cordgrass	Perennial	T				
<i>Atriplex</i> spp.		Perennial shrub	T				
<i>Kochia prostrata</i>		Perennial Shrub	T	17			
<i>Phalaris tuberosa</i>			MT	4.6	7.6		
<i>Halosarcia</i> spp.		Perennial	T				
<i>Prosopis</i> spp.	Mesquite						
<i>Acacia</i> spp.							
<i>Brassica napus</i>	Rape or Canola	Annual	MT				
<i>Melilotus alba</i>			MT				
<i>Melilotus</i>	Sweet clover	biennial	MT				

Additional forage plots are located at the Broadview Irrigation District and near the evaporation ponds in the Tulare Lake Drainage District (TLDD). Personal observation by this writer in the summer of 2000 indicated that grass stands were doing well and that cattle were grazing on the Broadview plots in August. The grasses grown at Broadview were *Sporobolus airoides* (Torr.) Torr, aka Willcox alkali sacaton; *Distichlis spicata*, saltgrass and *Polypogon monspeliensis*, rabbitsfoot grass. They also have a field of *Medicago sativa* (var. "Salado") and are including it in all their new plantings. Broadview reported in January 2001 that the cattle made good gains (personal communication). There is no actual data for yields, palatability or nutrient content for these projects at this time.

At TLDD *Distichlis spicata*, saltgrass and *Cyandon dactylon*, Bermudagrass, were observed by this writer growing well in the summer of 2000. In 1992, TLDD reported on growing NyPa Wild Wheat (*Distichlis* spp.) and other forages (not named) irrigated with water of salinity EC = 15 dS/m. These plots were reported as "doing well".

As a portion of the Grasslands Bypass Project (aka Active Land Management Program), land in the Mercy Springs water district is leased by the Panoche Drainage District. This land is drained by open earthen ditches but the Mercy Springs district chose not to participate in the bypass project; thus, there is no active outlet for drainage water. Panoche District has planted the fields to moderately sensitive alfalfa (*Medicago sativa*), moderately tolerant Sudan grass (*Sorghum sudanense*) and tolerant Bermuda grass (*Cyandon dactylon*). These crops are irrigated with a mixture of tailwater, groundwater pumped from a well near the southwest corner of the district and subsurface drainage water from the Panoche District. The water is applied mainly during the winter season when drainage water cannot be discharged to the San Luis Drain.

Data is kept on the quantity of applied water, the total dissolved solids (TDS) and soil salinity. The goal was to apply blended water with TDS not greater than 2000 mg/l (EC = 2.7 dS/m) but data from Jan.-Mar. 1999 indicated that the actual average salinity was closer to 3000 mg/l EC = 4.0 dS/m) and some applications were in the 4000-5000 (EC = 6.0 dS/m) range. In 1998 preliminary soil salinity samples were taken and at the end of 2000 the fields will be resampled to calculate a salt balance. The depth to water table in the area was between 1.2 and 1.8 meters below the surface during the period 07/24/1998 to 03/15/2000. Data is not available on yield, forage quality etc.

In the 1980's there was concern that there were not enough warm season grasses being grown in California. Warm season grasses, because of their tropical origins reach peak productivity later in the summer when cool season grasses decline in productivity due to the warm temperatures. Bermudagrass, sudangrass and dallisgrass (*Paspalum dilatatum*) were grown extensively and rhodesgrass (*Chloris gayana* Kunth) and kikuyugrass (*Pennisetum clandestinum*) had been tried.

UC Davis researchers selected 20 varieties, a mixture of warm season and cool season forages, to measure their productivity and forage value. These were planted on

April 14-15, 1980 grown and harvested for two years. One drawback of warm season crops is their inability to tolerate freezing winter temperatures. Lowest winter temperature at the test site was  $-4^{\circ}\text{C}$ . All of the grasses in the trial made it through the first winter, but four varieties of buffelgrass (*Cenchrus ciliaris* L.) and (*C.setigerus* Vahl.) did not survive. Seven other buffelgrasses survived the winter and had vigorous regrowth in the spring. Rhodesgrass, kikuyugrass and bermuda grass vigorously resumed spring growth. Elephant grass (*Pennisetum purpureum*) and pearl millet hybrids (*Pennisetum americanum*) regrew from old growth following the winter but by mid March it was evident the yields would drop off from the previous year. Elephant grass was the highest average yield for the two years, 17.9 tons/acre, but it also had the lowest level of crude protein, 6.4%, and nearly the highest fiber.

Bermudagrass (Tifton 44) had the second highest yield, 10.0 tons/acre and relatively high crude protein, 13.5%. Bermudagrass (CCI) had 18.5% crude protein and yields of 8.0 tons/acre. Other high yielders were sudangrass, limpograss (*Hemarthria* spp.), dallisgrass, guineagrass and kikuyugrass all having at least one variety yielding more than 8.0 tons/acre. Since these were productive it might be well to investigate the salt tolerance of these species for reuse in a forage production system.

Research in other countries on forages may have progressed much further than the research in the SJV.

From the Mediterranean basin, Le Houerou (1996) reports the following list for which large scale experiments have shown that most are able to produce 5 -20 tonnes of Dry Matter/ha/yr of good quality fodder with brackish water having EC = 5-15 dS/m.

#### Perennial grasses:

<i>Festuca arundinacea</i> (tall fescue)	<i>Paspalum distichum</i>
<i>Sporobolus ioclados</i>	<i>Phalaris aquatica</i> (alkali sacaton)
<i>Puccinellia cilata</i> Bor.	<i>Phalaris truncata</i>
<i>Chloris gayana</i> (Rhodes grass)	<i>Elymus elongates</i> (wild rye)
<i>Cynodon dactylon</i> L var <i>hirsutissimus</i> (Lit. & Maire) and var <i>villosus</i> Regel	
(Bermuda grass)	

#### Perennial legumes:

<i>Trifolium fragiferum</i> (strawberry clover)	<i>Hedysarum carnosum</i> (fleshy sainfoin)
<i>Lotus coniculatus</i> (birdsfoot trefoil)	<i>Tetragonolobus maritimus</i>
<i>Lotus roudairei</i> (trefoil)	

**Annual grasses:**

*Lolium rigidum* Gaudin (ryegrass)  
*Hordeum vulgare* L. (barley)

*Sorghum sudanense* (Piper) Stapf  
(Sudan grass)

**Annual legumes:**

*Melilotus albus*  
*Melilotus italicus*  
*Melilotus officinalis* (L.) Lam.  
(sweet clover)

*Medicago* spp. (alfalfa and the medics)  
*Trifolium resupinatum* (Persian clover)  
*Trifolium yanninicum* (yannina subclover)

Le Houerou reports that halophyte grass genera *Aeluropus*, *Sporobolus*, *Puccinellia*, and species *Ammophila arenaria* L. Link and *Agropyron* spp. (*Agropyron* are now called *Thinopyron* or *Lophopyron*) were able to grow when the soil solution was EC 10-15 dS/m or above. The annual *Hordeum maritimum* was also growing under the above soil conditions. He also believes that species of *Haloxylon*, *Kochia* and *Maireana* are possible forage species and recommends the biennial fodder legume *Hedysarum carnosum*.

Malcolm (1996a) reports from Australia, "Halophytic grasses of forage value include *Sporobolus* spp., *Aeluropus* spp. and *Distichlis* spp. all of which possess salt glands." Other highly salt tolerant grasses include *Puccinellia* spp. which avoid highest salinity levels at sites by going dormant in the summer. *Paspalum vaginatum* Sw. (salt water couch) is very tolerant of waterlogging. *Diplachne fusca* (L.) Beauv. is tolerant of prolonged waterlogging and high pH, but is less salt tolerant than other halophytes. Malcom recommends *Puccinellia ciliata* Bor. for both mild and moderate saline sites. He recommends *Thinopyrum elongatum* (tall wheatgrass) and *Cynodon dactylon* (L.) Pers. (Bermuda grass) for only mild sites. He does not recommend any grasses for severely salt affected sites. No discussion is made of irrigation of these plants with saline water.

Malcom (1996a) does mention *Trifolium fagiferum* (strawberry clover) as a plant suited to mild saline sites without waterlogging to provide a legume in the pasture mix. He (Malcom 1996b) also recommends addition of nitrogen to the *Puccinellia* and *Thinopyron* pastures in the amount of 23 kg/ha in autumn and 45-60 kg/ha in late winter. He reports the resulting growth of grasses on salt-affected lands has supported 48 dry sheep equivalents per ha for two months and after being harvested provided 300kg/ha of seed for sale.

Marcar (1987) working in Australia also reported on the salt tolerance of the genus *Lolium* (ryegrass) during germination and growth. He grew three representative species; Wimmera (*L. rigidum*), Italian (*L. multiflorum*) and perennial (*L. perenne*) of ryegrass in solutions of increasing salinities and compared them with known salt tolerant species saltmarshgrass (*Puccinellia ciliata*) and tall wheatgrass (*Elytrigia pontica*)<sup>9</sup>. Marcar found that germination was insensitive for all species with NaCl concentrations

<sup>9</sup> I have obtained at least three scientific names for the common name tall wheatgrass, *Agropyron elongatum*, *Thinopyron elongatum* and now *Elytrigia pontica*. Are they the same?

up to 200 moles/meter<sup>3</sup> (about 14.6 dS/m). Seeds were germinated in petri dishes and plants were grown in pots with coarse river sand. Higher concentrations were tolerated only by the two control species and *L. multiflorum*. During growth only the two tolerant grasses did well; ryegrasses were found to be only moderately tolerant of salt.

In Israel (Pasternak and Nerd, 1996) at least two types of experiments have been attempted. At a seawater irrigation trial south of Ashkelon a number of plants were irrigated with seawater EC=54 dS/m and with 15% seawater, EC=9 dS/m. Of eight grass species tried only three, *Aeluropus lagopoides*, *A. littoralis* and *Distichlis palmeri* performed well under the seawater strength and none of these were considered as suitable for forage. The authors recommend *Distichlis palmeri* for grass in landscape areas to be irrigated with seawater, but warn the grass may be prickly. The other species used were *Elymus sabulosus*, *Leptochola fusca*, *Paspalum vaginatum*, *Puccinellia cilata* and *Sporobolus virginicus*, which apparently survived and grew with the 9 dS/m irrigation water.

In a trial at the Ramat Negev Experimental Station the performance of five known salt tolerant grasses and alfalfa were tested under a range of irrigation water salinity levels from 1.2 – 10 dS/m. The forage species were Rhodes grass (*Chloris gayana* Kunth) cv. common, Bermuda grass (*Cynodon dactylon* L. Pers.) cv. Suwanee, Kallar grass (*Leptochola fusca* L. Kunth.), salt (spike) grass (*Distichlis spicata* L.), seashore paspalum (*Paspalum vaginatum* Swartz), and alfalfa (*Medicago sativa* L.) cv. Gilboa. Dry matter yield equations are given below for two years 1990 and 1991. Salt grass, Bermuda grass and *Paspalum vaginatum* were the most salt tolerant. The first two species showed no yield decrease at soil EC<sub>e</sub> of 14 dS/m. Salt grass is by far the most salt tolerant and drought tolerant. Pasternak and Nerd recommend this latter species for domestication and improvement for both forage and pasture.

**Table 12: Effect of soil salinity on dry matter production of six forages in 1990 and 1991.**

Forage	1990 Yield Eq.	R sq. value	1991 Yield Eq.	r sq. value
Alfalfa	$Y = 0.099X + 2.63$	0.95	$Y = 0.106X + 2.85$	0.70
Bermuda	$Y = 0.005X + 2.67$	N.S.	$Y = 0.003X + 3.88$	N.S.
Kallar Grass	$Y = 0.097X + 2.71$	0.80		
Paspalum	$Y = 0.006X + 3.09$	N.S.	$Y = 0.114X + 4.60$	0.68
Rhodes	$Y = 0.083X + 3.57$	0.69	$Y = 0.319X + 6.57$	0.91
Salt grass	$Y = 0.005X + 2.57$	N.S.	$Y = 0.075X + 2.85$	0.68

Ahamad and Ismail (1996) report that various species of *Agropyron* and *Elymus* are well adapted grasses in winter rain areas. *A. desertorum* and *E. hispidus* subsp. *hispidus* are being grown in Iran. *A. cristatum* (crested wheatgrass) and *E. hispidus* subsp. *hispidus* are grown in Morocco. *Thinopyrum elongatum* (Host) D.R. Dewey aka. (*Agropyron elongatum*, tall wheatgrass) grows well in the mild winter and semi arid regions of Tunisia. It can tolerate 7.5 dS/m without reduction in growth.

In India, Kallar (Karnal) grass (*Leptochloa fusca*) and Para grass (*Brachiaria mutica*) were grown with and without pyrites on alkali loams in Kanpur. In Jobner Rhodes grass (*Cloris gayana*), blue panic (*P. antidotale*) and Para grass were irrigated with saline water EC = 16 dS/m yielded respectively 41.5, 31.1 and 31.0 Mg/ha. Other grasses tried were Bermuda grass (*Cynodon dactylon*), Napier grass ( ), (*Cenchrus ciliaris*), *Panicum laevifolium*, Gatton panic (*P. maximum*), and *P. virginatum*.

Chhabra (1996) recommends *Suaeda maritime*, *Leptochloa fusca*, *Cynodon dactylon*, *Sporobolus marginatus*, *Brachiaria mutica*, *Chloris gayana*, *Panicum maximum* and *Panicum antidotale* for alkali soils. For saline soils *Sporobolus pallida*, *Cynodon dactylon*, *Agropyron elongatum*, eel grass (*Zostera marina*), cord grass (*Spartina alternifolia*) and Jajoba/Hohoba/goatnut (*Simmondsia chinensis*).

#### Kallar Grass (*Leptochloa fusca*)

This grass has been known at least since 1929 when it was described and its distribution reported in Egypt, India, Sri Lanka, Tropical Africa, Asia (Sind & Pakistan), and Australia. Earlier it was known as *Diplachne fusca* in the Gramineae family. In 1954, it was found growing in rice fields and in marshy places in the Lahore district, Pakistan. (Malik, 1986).

Malik et al. (1986) also report that it is a C-4 plant meaning that it can convert up to 6% of the received solar energy and take up carbon dioxide at very low concentrations. It also can survive salinities up to 40 dS/m and can fix up to 80% of its own nitrogen requirements. It has been successfully grown on soils with EC<sub>e</sub> of 12-14 dS/m, SAR 150 and pH 9-10. It has been determined that it can be economically grown in salinities up to 22 dS/m which is near the relative yield 50% reduction point. Malik et al., reported that the yield curve was determined by growing the plant in gravel filled pots with salinity variations from 3 to 40 dS/m using an artificial salt mixture of NaCl, Na<sub>2</sub>SO<sub>4</sub>, CaCl<sub>2</sub>, and MgCl<sub>2</sub> in a 4:10:5:1 ratio. Yield reductions began immediately at the lowest salinities and Oster has estimated the yield reduction slope as -9.1 (personal communication). Unlike other salt tolerant species the plant does maintain a high K<sup>+</sup>/Na<sup>+</sup> ratio by exuding sodium chloride through the leaves.

The germination from seed is generally poor, but fresh cutting buried in wet soils do root and grow profusely. The plant grows to a height of 4 to 5 feet and produces up to 40 tons of green biomass per ha.

## Atriplex

Glenn et al., (1981) in examination of Arizona's agricultural water budget proposed using C-4 halophytes to provide a forage to replace alfalfa in livestock production. Using a water cost ratio defined as g H<sub>2</sub>O/ g DW, which is the quantity of water transpired per unit dry matter produced. This can be measured in three different ways: one may compare the transpiration and photosynthesis for a single leaf; or measure the dry matter verses the total water used in potted plants; or compare dry matter yield to irrigation water used under field conditions. Glenn noted that in the latter type study it is not always easy to measure the water losses due to deep percolation, runoff and surface evaporation which tends to overestimate water consumption by the plant. Instantaneous measurements on a single leaf may not account for water and carbon losses at night, therefore, it is not surprising that the three methods may yield different results.

Glenn et al., (1981) report that in general it has been found by researchers that C-4 plants in general have water use efficiencies of nearly twice the C-3 crops. They also report that Atriplex has transpiration to dry matter ratios ranging from 87 to 232 compared to alfalfa at 814. Goodin (1979) in west Texas comparing alfalfa with *Atriplex canescens* found that equivalent yields of *Atriplex* were obtained using only 15-20% of the water used by alfalfa. Consider also that *Atriplex* species may also be able to grow in water considerably saltier than salt sensitive alfalfa and a substantial change in agricultural water use may be accomplished by changing forage crops.

As part of the Environmental Research Laboratory (ERL) experiments near Puerto Penasco, Sonora, Mexico several halophyte plants were grown using hyper saline irrigation water (40,000 ppm) and then tested for nutritional value (Glenn et al., 1982). *Atriplex barclayana*, *A. lentiformis* and *Salicornia europaea* were grown with the nutrient enriched seawater. Harvested material was sun dried, stored at room temperature, seeds and fruits separated, by hand; then, the material was ground in a Wiley mill through a 20 mesh screen. The plant material was then chemically analyzed using a commercial laboratory in Tucson, AZ by standard analytical procedures. Protein contents of the plants were *Atriplex barclayana* 18.7%; *A. lentiformis*, 12.4%; and *Salicornia europaea*, 14.4%. Ash and cation contents were relatively high in the mature plants and oxalate ions were a problem when the material was fed to chicken and mice at rates that exceeded 15% of the total diet. To eliminate the poisoning effects the *Atriplex barclayana*, and *A. lentiformis* plant material had to be soaked in a saturated calcium hydroxide solution.

O'Leary et al., (1985) report on growing *Atriplex barclayana*, *A. lentiformis*, *A. nummularia*, *A. canescens*, *A. glauca*, *A. polycarpa*, *A. repanda*, *A. patula*, *Batis maritima*, *Cressa truxillensis* and *Salicornia europaea* using seawater for irrigation at the ERL site in Mexico. They noted that the highest productivity, 1800-1500 g/m<sup>2</sup>, came from the native species. (*A. nummularia*, *A. glauca*, *A. repanda* and *A. patula* are non-native.) The highest yielding species was *A. lentiformis* and it had 16.7% protein, 1.3% fat, and 14.1% fiber all favorable, but it also had 26.8% ash and 3.6% oxalate diminishing its favorability as animal feed. Frequent cutting also diminished the yield for the plant with 20% mortality when cut three or more times per season. *Atriplex nummularia* and

*A. barclayana* were 160 to 170% more productive when they were harvested more frequently putting them into favorable comparison to alfalfa grown with non-saline water. The plants were fed to goats and were found to be acceptable and palatable. Due to the high ash content it is best that they make up not more than 25% of the animals total diet.

The ERL group also evaluated *Atriplex nummularia* and *A. lentiformis* using brackish water from an artesian geothermal well at Safford, AZ. (Watson et al., 1987) The water had EC 9.3 – 10.3 dS/m, SAR 44, sulfate ion 22-31 meq/l and fluorine 5-8 ppm making it totally unsuitable for irrigating most commercial agricultural crops. The soil was initially a non-saline, non-sodic as defined by Handbook 60 (US Salinity Laboratory Staff, 1954) but within eight weeks after the first irrigation had become saline-sodic. The highest biomass yields were 14.7 tonnes/ha *A. lentiformis* and 12.3 tonnes/ha for the *A. nummularia*. The quality of the forage seemed to decrease as the season progressed, but oxalate ion also decreased with time. The feed value of *A. nummularia* was superior to *A. lentiformis*. The authors believe that both species show a potential for forage production using water unsuitable for other crops.

In the San Joaquin Valley (SJV) Watson from the ERL set up test plots at Murrieta farms and other locations to screen *Atriplex* for use in Agroforestry/IFDM sites (Watson, 1990a, 1990b). Names and origins of the *Atriplex* accessions used in the 1988 field trials are listed in Table 13.

**Table 13: Names and origins of the *Atriplex* accessions and place of origin.**

Species	Origin
<i>A. barclayana</i> (Benth.) Dietr.spp barclayana	Baja California, Mexico
<i>A. barclayana</i> ssp <i>sonorae</i> (Standl.) Hall & Clem.	Baja California, Mexico
<i>A. undulata</i> Dietr.	Argentina, South America
<i>A. deserticola</i> Phil.	Chile, South America
<i>A. cinerea</i> Poir. ssp <i>bolusii</i> (C.H. Wr.) Aell	Cape Peninsula, South Africa
<i>A. vestita</i> (Thunb.) Aell	Cape Peninsula, South Africa
<i>A. halimus</i> ssp <i>halimus</i> L.	Israel
<i>A. lentiformis</i> ssp <i>breweri</i> (Wats.) Hall and Clem.	S&S Seed, Carpenteria, CA
<i>A. lentiformis</i> (Torr.) Wats. ssp <i>lentiformis</i>	Plant Materials Center, Tucson, AZ
<i>A. canescens</i> ssp <i>macropoda</i> (Rose & Standl.) Hall and Clem	Baja California, Mexico
<i>A. canescens</i> (Pursh.) Nutt. cv 'Marana'	Plant Materials Center, Lockford, CA
<i>A. canescens</i> (Pursh.) Nutt. ssp <i>canescens</i>	Arizona
<i>A. nummularia</i> Lindl.	Pecoff Brothers, Escondido, CA
<i>A. polycarpa</i> (Torr.) Wats.	Native Plants Inc., Lehi, UT
<i>A. rosea</i> L.	Baja California, Mexico
<i>A. holocarpa</i> F. Muell.	Australia
<i>A. angulata</i> Benth	Australia
<i>A. lindleyi</i> ssp <i>inflata</i> F. Muel.) P.G. Wilson	Australia

Plants were started in random plots by both sowing of seed and transplanting of individual stems. The plants were planted in rows with a 0.76m width spacing with seed being sown at a depth of 0.5 – 1.0 cm. The spacing between transplants in the rows was 0.61 – 0.91m. There was 90% or greater survival by the transplants and seedlings were

present after one month with additional seedlings appearing throughout the growing season.

Since the main purpose for using halophytes in the SJV is to reduce the volume of drainage water, it is important to determine water use. In green house studies with *A. nummularia* at Davis, CA, Sachs et al. (1990) determined that irrigation with saline water in the concentration range  $EC = 10-12$  dS/m would reduce water consumption from about 1.25 acre-ft per year to just below 1.0 acre-ft per year (20-25% reduction in water use). The soil leachate from these trials performed in sandy soils had concentrations  $EC = 20-22$  dS/m. Little reduction in growth rate as measured by stem elongation was reported, but the researchers reported that their estimates of water use were conservative and were based upon plants irrigated to field capacity with a 50-75% leaching fraction with excellent drainage.

Trials at Murrieta Farms indicated average first cut yields of 3000 kg/ha. Many species recovered and provided at least two harvests during the initial year. It was demonstrated that it is possible to cut and bale these plants as with ordinary forages. Harvest yields and nutritive value were highest for *Atriplex barclayana* (Benth.) Dietr.

Watson (1990b) stated, " Even though *Atriplex* can tolerate soil salinities and levels of trace elements significantly higher than those suitable for irrigated field crops, the long term effect of continuous irrigation with saline drainage water on productivity and forage quality would need to be determined. The soil/water management practices to provide adequate drainage and other soil-related aspects are critical factors in using saline drainage water for irrigating halophytes (Glenn and O'Leary, 1985; O'Leary 1986). The hazards of soils becoming excessively saline or sodic and the appropriate reclamation strategies would also need to be considered. Although studies of *Atriplex* irrigated with highly saline water have been documented, little is known about the relative growth potential and salt tolerance for the different *Atriplex* species under long term cultivated conditions. Establishing salt tolerance data for the different species and developing guidelines for irrigation, drainage and cultural management practices are required before introducing *Atriplex* to irrigated farming on a larger scale."

Watson and O'Leary (1993) reported on irrigation of *Atriplex* species with saline water ( $EC = 18$  dS/m) in the SJV. Plants were cut and baled four times over a 27 month period. Yields were as high as 9.9 tons/ha per cutting, with total yields for the four cuttings approaching 20 tons/ha. The material had to be blended with alfalfa to make it palatable to livestock.

*Atriplex* was also grown at the Red Rock Ranch site in the SJV. It is growing with other halophytes and is being irrigated with drainage water 12 – 15 dS/m. The species being used is not clearly spelled out, but *A. canescens*, ('Marana' fourwing saltbush) *A. lentiformis* ('Casa' quail bush) and *A. patula* var. *hastada* (fat-hen) are listed in the report (Cervinka et al., 1999). Benes from California State University – Fresno is determining the ET coefficients for the halophyte plants and reports that she is working with *A. nummularia* (old man saltbush). This research is finding that the *Atriplex* has

greater ET than saltgrass, but less than *Salicornia*. They are unable to attach quantitative ET results to these species without further data (personal communication, 2000).

In 1990's, during the *Atriplex* trials in the SJV the Integrated Pest Control Branch of the California Department of Food and Agriculture raised the issue that *Atriplex* is a host plant for the leafhopper (BLH) that spreads the curly top virus (CTV) to sugar beets. It may be incompatible for sugar beets and *Atriplex* to be grown on an extensive basis although it is a native species to the area. In a report to the Tulare Lake Drainage District, Duffus et al. (1991) found *A. barclayana*, *A. camarones*, *A. canescens*, *A. canescens* subspecies *macropoda*, *A. cinera*, *A. deserticola*, *A. halimus*, *A. nummularia* and *A. sagittifolia* were all found to be poor hosts of the BLH and should not be considered threats to CTV control efforts. The naturally infected species are *A. argenta*, *A. bracteosa*, *A. fruticulosa*, *A. patula* and *A. rosea*. There is an additional list of *Atriplex* species that could be experimentally infected.

*Atriplex* introduced into many Mediterranean areas (Algeria, Tunisia, Morocco and Libya). Several thousand ha have been planted in the basin. *Atriplex nummularia*, *A. halimifolia* and *A. lentiformis* have shown good tolerance to drought. Also in Libya, *A. canescens* and *Acaia saligna* have been planted together on several thousand acres of grazing lands and have shown a 100% increase in dry matter production with irrigation.

In Australia, *A. ammicola* Wilson and *A. undulata* De Dist are promising shrub species for reclaiming salt affected lands. *A. nummularia* is being promoted in New South Wales as a crop for recovery of native pastures. Condon and Sipe, (unpublished) state that with intermittent heavy grazing it is 8 to 10 times better than native pastures and 2-4 times better than sown pastures in these areas. It can be as productive as Lucerne (alfalfa) with much less water use.

Trumble et al. (2000) have been screening 62 *Atriplex* lines for their ability to selectively accumulate selenium in the presence of high sulfate content, which is characteristic of the drainage water in the SJV. Insect bioassays were also conducted on 30 of the lines to determine if there would be a risk in insect proliferation to pest levels. The goal was phytoremediation of selenium using *Atriplex* without increasing the potential of spreading insect problems to existing agronomic crops. Although the research is ongoing, they have concluded that *A. patula patula*, *A. spongiosa*, 415862, *A. hortensis hortensis*, *A. hortensis* 379088 and *A. hortensis* 379092 are promising phytoremediators of selenium and produce high biomass. The preliminary analysis also indicates that these species may aid in removing insect pests from the region.

## Salicornia

*Salicornia* has been known for some time in Europe as samphire, its older name being "poor man's asparagus". Sir Thomas More wrote almost 500 years ago that "samphire improved many a knave's pottage ... affording him a relish to accompany his mouthful of salt meat" (Clark, 1994). It is today considered a gourmet food and is eaten in the south of France and the British Isles, particularly East Anglia. Elizabeth Schnieder in Uncommon Fruits and Vegetables: a common sense guide, has written, "when young it is crisp, pleasantly deep sea tasting, an unusual summer pleasure". Another description is, "very crunchy and salty like brined baby string beans" (Clark, 1994). However, others maintain that the name samphire is reserved for *Crithmum maritimum*, also known as sea fennel, which grows on the sea cliffsides of Great Britain and in northwest Europe.

*Salicornia bigelovii* is native to the western coast of North America and was investigated as a potential halophyte food crop by the Environmental Research Laboratory (ERL) in Tucson, Arizona beginning in the 1970's. The ERL researchers screened nearly 800 halophyte plants for potential sea water and brackish water productivity and determined *Salicornia bigelovii* the winner in terms of oilseed and green-matter productivity. It was found to grow well using sea water for irrigation at a research station in Sonora, Mexico. More importantly, the seeds were found to have an oil content of 30% by weight (compared to 17-20% for soybeans) and the *Salicornia* oil was 72% linoleic acid – a healthy polyunsaturated fat (Clark, 1994). The residual seed meal also found to contain 40% protein and be palatable for livestock.

For ten years *Salicornia bigelovii* was selectively developed along the coast of the Gulf of California (Sea of Cortez); the seeds from the best plants selected progressively sowing sturdier, better producing plants. Trial plots were also grown in the United Arab Emirates, Egypt, Kuwait and Saudi Arabia. At Jubail Industrial City in Saudi Arabia, a 2 ha field trial produced oil seed yields as high as 3.5 tons/ha (equivalent to 70 bu/acre). The salt content of the irrigation water used, 40,000 ppm, would have killed most other plants, but *Salicornia* has been shown to tolerate 50,000 ppm water without blighting. The Saudi government was so pleased with the test results that they funded project at Ras al-Zawr to grow 250 hectares of *Salicornia*. They have five 50 ha center pivot irrigation systems pumping 28 cubic meters of sea water per minute. It takes 6 ½ hours for the arms to complete one circuit and they are often kept running continuously. ERL has advised the Saudi's to irrigate with 25% more water than the crop requires to flush the salt below the root level of the crop and back into the sea (Clark, 1994). Yields in 1993-94 were not as large as those anticipated from the results at the smaller plots. Since there are no oil production facilities in Saudi the crop was harvested and baled for dairy forage. Some crunchy green tips were air lifted to Europe for test marketing. Other large scale production of *Salicornia bigelovii* has begun in India and by 1994 inquiries had been made by Iran, Somalia, Egypt and Syria.

In the San Joaquin Valley (SJV) of California, Grattan et al. (1999) obtained seed from the researchers in Arizona to begin to determine the growth characteristics of *Salicornia bigelovii* when irrigated with sulfate dominated groundwaters found in the

SJV. Two field plots were planted in June 1995: a 1 ½ acre plot near Mendota and a 2 ½ acre plot near Five Points. At Mendota the plot was irrigated with water having a salinity of 30 dS/m (approximately 2/3 the salinity of sea water). A good stand was established and the plants appeared to thrive. The larger plot failed to grow and it was later determined that saline water is required for establishment of this plant (Grattan, personal communication)

Also in 1995 greenhouse experiments were begun at the Westside Research and Extension Center in Five Points, CA. Plants were grown in SJV drainage water and seawater at three different salinity levels: 10-20 dS/m, 20-40 dS/m and 40-60 dS/m. Plant height, fresh weight and root and shoot biomass were monitored. Early indications were that *Salicornia bigelovii* did not grow quite as well in the SJV saline water as it did with sea water. (Mitchell et al. 1995)

“A drainage water reuse concept has been proposed for the San Joaquin Valley of California where saline drainage water is used to irrigate progressively more salt-tolerant crops whereby halophytes are the final crop in the sequence, prior to disposal. *Salicornia bigelovii* has emerged as a promising halophyte” Grattan et al. (1999). Not only has it been shown that this native coastal plant can grow and thrive in the desiccating conditions of the valley when irrigated with Na-sulfate drainage water (29 dS/m and > 25 mg/L B), but this leafless plant can maintain evapotranspiration (ET) rates comparable to reference (ET<sub>o</sub>).

This plant also has economic potential. Under irrigation with diluted seawater, its seed has been reported to produce an oil high in polyunsaturated fat comparable to soybean. After oil extraction the remaining high protein meal (43% protein) can be fed to animals (Glenn et al., 1991). When harvested prior to seed maturity it has been successfully fed to small ruminants.

Greenhouse studies were undertaken to find if SJV drainage water could be used to irrigate *Salicornia* and to study its tolerance to boron. Results in 1996, 1997 and 1998 seemed to indicate favorable response to the drainage water.

Field studies were undertaken on a one acre agroforestry study site about three miles south of Mendota. *Salicornia* was planted June 1, 1995 and has subsequently reseeded naturally. Vegetative growth was large in 1996 but less favorable in 1997. Seed yield was disappointing when compared to the results Glenn obtained in Sonora, Mexico. The plant does have high ET rates and may still have significant use as a final stage halophyte in a drainwater reduction program.

## Pistachios

This information based upon "Potential for Utilizing Blended Drainage Water Irrigating West Side, San Joaquin Valley Pistachios" Ferguson, L., et al. UC Salinity Drainage Program 1997-98 Annual Report.

The results demonstrate pistachios tolerate irrigation with blended drainage water up to 8.0 dS/m. (Blended water up to 12.0 dS/m was also used in crop season 1997, but results were not provided in this report.)

Four major rootstocks are used in the SJV. "Previous studies investigating the salt tolerance of pistachio have been conducted using pistachios other than Kerman (*Pistacia vera* L., cv. Kerman) in a greenhouse setting with sodium chloride laced irrigations (see Ferguson et al. 1998 for references). Ferguson et al. (1998) also report that Behboudian (1986), again in a greenhouse setting with sodium chloride laced irrigations, using 1 year old P. Atlantica rootstock budded with 'Kerman' concluded that *P. vera* is highly salt tolerant and Picchioni (1990) reported three of the currently planted, though less popular, pistachio rootstock seedlings did not manifest significant reductions in growth until electrical conductivity of the irrigation water ( $EC_w$ ) of 13.8 dS/m and an electrical conductivity of the saturated soil extract ( $EC_e$ ) of 17.9 dS/m were imposed in a two season outdoor lysimeter test.

Ferguson, et al., (2000) reported on the salinity tolerance in tanks. Generally, all rootstocks were tolerant of salinities up to  $EC = 8$  dS/m. Beyond that level there were reductions in biomass accumulation and trunk diameter for all of the rootstocks except Atlantica. Atlantica showed more tolerance to the  $EC = 12$  dS/m by having no reduction in biomass and only a 7% reduction in trunk diameter. By  $EC = 16$  dS/m all rootstocks had growth reductions of at least 50%. The important conclusion of the salinity tank trials was that the rootstocks appeared to have reverse tolerance as that observed in the field trials. Rootstock PGI appeared to have the best salt tolerance in the field, but had the poorest in the tank trials. It is suspected that since the tanks were well drained and the fields may not have been, there was a combination of salt tolerance and water logging tested in the fields that was not tested in the tank experiment.

Further reports in the literature suggest pistachios are highly tolerant of boron and have the ability to tolerate sodium through the mechanism of root and basal stem storage (Walker et al., 1987)."

Grattan in personal communication May 22, 2000, stated that he thought the above experiments were biased by the fan irrigation system. There may have been times during the growing season when the plant roots could have reached soil portions with a non-saline water supply. Sand tank experiments, underway at the salinity lab, may provide more complete answers.